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TITLE OF THE INVENTION (500 characters max)

SYSTEMS AND METHODS FOR SURGICAL NAVIGATION

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Respectfully submitted,

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SYSTEMS AND METHODS FOR SURGICAL NAVIGATION

BACKGROUND

In recent years, the medical community has been increasingly focused on minimizing the invasiveness of surgical procedures. Advances in imaging technology and instrumentation have enabled procedures using minimally-invasive surgery with very small incisions. Growth in this category is being driven by a reduction in morbidity relative to traditional open procedures, because the smaller incisions minimize damage to healthy tissue, reduce patient pain, and speed patient recovery. The introduction of miniature CCD cameras and their associated micro-electronics has broadened the application of endoscopy from an occasional biopsy to full minimally-invasive surgical ablation and aspiration.

Minimally-invasive endoscopic surgery offers advantages of a reduced likelihood of intraoperative and post-operative complications, less pain, and faster patient recovery. However, the small field of view, the lack of orientation cues, and the presence of blood and obscuring tissues combine to make video endoscopic procedures in general disorienting and challenging to perform. Modern volumetric surgical navigation techniques have promised better exposure and orientation for minimally-invasive procedures, but the effective use of current surgical navigation techniques for soft tissue endoscopy is still hampered by two difficulties: accurately tracking all six degrees of freedom (DOF) on a flexible endoscope within the body, and compensating for tissue deformations and target movements during an interventional procedure.

To illustrate, when using an endoscope, the surgeon's vision is limited to the camera's narrow field of view and the lens is often obstructed by blood or fog, resulting in the surgeon suffering a loss of orientation. Moreover, endoscopes can display only visible surfaces and it is therefore often difficult to visualize tumors, vessels, and other anatomical structures that lie beneath opaque tissue (e.g., targeting of pancreatic adenocarcinomas via gastro-intestinal endoscopy, or targeting of submucosal lesions to sample peri-intestinal structures such as masses in the liver, or targeting of subluminal lesion in the bronchi).

Recently, image-guided therapy (IGT) systems have been introduced. These systems complement conventional endoscopy and have been used predominantly in neurological, sinus, and spinal surgery, where bony or marker-based registration can provide adequate target accuracy using pre-operative images (typically 1–3 mm). While IGT enhances the surgeon's ability to direct instruments and target specific anatomical structures, in soft tissue these systems lack sufficient targeting accuracy due to intra-operative tissue movement and deformation. In addition, since an endoscope provides a video representation of a 3D environment, it is difficult to correlate the conventional, purely 2D IGT images with the endoscope video. Correlation of information obtained from intra-operative 3D ultrasonic imaging with video endoscopy can significantly improve the accuracy of localization and targeting in minimally-invasive IGT procedures.

Until the mid 1990's, the most common use of image guidance was for stereotactic biopsies, in which a surgical trajectory device and a frame of reference were used. Traditional frame-based methods of stereotaxis defined the intracranial anatomy with reference to a set of fiducial markers, which were attached to a frame that was

screwed into the patient's skull. These fiducials were measured on pre-operative tomographic (MRI or CT) images.

A trajectory-enforcement device was placed on top of the frame of reference and used to guide the biopsy tool to the target lesion, based on prior calculations obtained from pre-operative data. The use of a mechanical frame allowed for high localization accuracy, but caused patient discomfort, limited surgical flexibility, and did not allow the surgeon to visualize the approach of the biopsy tool to the lesion. There has been a gradual emergence of image guided techniques that eliminate the need for the frame altogether. The first frameless stereotactic system used an articulated robotic arm to register pre-operative imaging with the patient's anatomy in the operating room. This was followed by the use of acoustic devices for tracking instruments in the operating environment. The acoustic devices eventually were superceded by optical tracking systems, which use a camera and infrared diodes (or reflectors) attached to a moving object to accurately track its position and orientation. These systems use markers placed externally on the patient to register pre-operative imaging with the patient's anatomy in the operating room. Such intra-operative navigation techniques use pre-operative CT or MR images to provide localized information during surgery. In addition, all systems enhance intra-operative localization by providing feedback regarding the location of the surgical instruments with respect to 2D preoperative data.

Until recently, volumetric surgical navigation has been limited by the lack of the computational power required to produce real-time 3D images. Today the use of various volumetric imaging modalities has progressed to permit the physician to visualize and quantify the extent of disease in 3D in order to plan and execute treatment. Today,

systems are able to provide real-time fusion of pre-operative 3D data with intraoperative 2D data images from video cameras, ultrasound probes, surgical microscopes, and endoscopes. These systems have been used predominantly in neurological, sinus, and spinal surgery, where direct access to the pre-operative data plays a major role in the execution of the surgical task. This is despite the fact that, because of movement and deformation of the tissue during the surgery, these IGT procedures tend to lose their spatial registration with respect to the pre-operatively acquired image.

SUMMARY

In one aspect, a method for assisting a user in guiding a medical instrument to a subsurface target site in a patient includes generating one or more intraoperative images on which a spatial feature of a patient target site can be indicated, indicating a spatial feature of the target site on said image(s), using the the spatial feature of the target site indicated on said image(s) to determine 3-D coordinates of the target site spatial feature in a reference coordinate system, tracking the position of the instrument in the reference coordinate system, projecting onto a display device, a view field as seen from a known position and, optionally, a known orientation, with respect to the tool, in the reference coordinate system, and projecting onto the displayed view field, indicia whose states are related to the indicated spatial feature of the target site with respect to said known position and, optionally, said known orientation, whereby the user, by observing the states of said indicia, can guide the instrument toward the target site by moving the instrument so that said indicia are placed or held in a given state in the displayed field of view.

The generating includes using an ultrasonic source to generate an ultrasonic image of the patient, and the 3-D coordinates of a spatial feature indicated on said image are determined from the 2-D coordinates of the spatial feature on the image and the position of the ultrasonic source. The medical instrument can be an endoscope and the view field projected onto the display device can be the image seen by the endoscope. The view field projected onto the display device can be that seen from the tip-end position and orientation of the medical instrument having a defined field of view. The view field projected onto the display device can be that seen from a position along the axis of

instrument that is different from the target than the tip-end position of the medical instrument. The target site spatial feature indicated can be a volume or area, and said indicia are arranged in a geometric pattern which defines the boundary of the indicated spatial feature. The target site spatial feature indicated can be a volume, area or point, and said indicia are arranged in a geometric pattern that indicates the position of a point within the target site. The spacing between or among indicia can be indicative of the distance of the instrument from the target-site position. The size or shape of the individual indicia can indicate the distance of the instrument from the target-site position. The size or shape of individual indicia can also be indicative of the orientation of said tool. The indicating includes indicating on each image, a second spatial feature which, together with the first-indicated spatial feature, defines a surgical trajectory on the displayed image. The instrument can indicate on a patient surface region, an entry point that defines, with said indicated spatial feature, a surgical trajectory on the displayed image. The surgical trajectory on the displayed image can be indicated by two sets of indicia, one set corresponding to the first-indicated spatial feature and the second, by the second spatial feature or entry point indicated. The surgical trajectory on the displayed image can be indicated by a geometric object defined, at its end regions, by the first-indicated spatial feature and the second spatial feature or entry point indicated.

In another aspect, a system for guiding a medical instrument to a target site in a patient includes an imaging device for generating one or more intraoperative images, on which spatial features of a patient target site can be defined in a 3-dimensional coordinate system, a tracking system for tracking the position and optionally, the orientation of the medical instrument and imaging device in a reference coordinate system, an indicator by

which a user can indicate a spatial feature of a target site on such image(s), a display device, an electronic computer operably connected to said tracking system, display device, and indicator, and computer-readable code which is operable, when used to control the operation of the computer, to perform (i) recording target-site spatial information indicated by the user on said image(s), through the use of said indicator, (ii) determining from the spatial feature of the target site indicated on said image(s), 3-D coordinates of the target-site spatial feature in a reference coordinate system, (iii) tracking the position of the instrument in the reference coordinate system, (iv) projecting onto a display device, a view field as seen from a known position and, optionally, a known orientation, with respect to the tool, in the reference coordinate system, and (v) projecting onto the displayed view field, indicia whose states indicate the indicated spatial feature of the target site with respect to said known position and, optionally, said known orientation, whereby the user, by observing the states of said indicia, can guide the instrument toward the target site by moving the instrument so that said indicia are placed or held in a given state in the displayed field of view.

Implementations of the above aspect may include one or more of the following. The imaging device can be an ultrasonic imaging device capable of generating digitized images of the patient target site from any position, respectively, and said tracking device is operable to record the positions of the imaging device at said two positions. The medical instrument can be an endoscope and the view field projected onto the display device is the image seen by the endoscope.

In yet another aspect, machine readable code in a system designed to assist a user in guiding a medical instrument to a target site in a patient, said system including (a) an

imaging device for generating one or more intraoperative images, on which a patient target site can be defined in a 3-dimensional coordinate system, (b) a tracking system for tracking the position and optionally, the orientation of the medical instrument and imaging device in a reference coordinate system, (c) an indicator by which a user can indicate a spatial feature of a target site on such image(s), (d) a display device, and (e) an electronic computer operably connected to said tracking system, display device, and indicator, and said code being operable, when used to control the operation of said computer, to (i) record target-site spatial information indicated by the user on said image(s), through the use of said indicator, (ii) determine from the spatial feature of the target site indicated on said image(s), 3-D coordinates of the target-site spatial feature in a reference coordinate system, (iii) track the position of the instrument in the reference coordinate system, (iv) project onto a display device, a view field as seen from a known position and, optionally, a known orientation, with respect to the tool, in the reference coordinate system, and (v) project onto the displayed view field, indicia whose states indicate the indicated spatial feature of the target site with respect to said known position and, optionally, said known orientation, whereby the user, by observing the states of said indicia, can guide the instrument toward the target site by moving the instrument so that said indicia are placed or held in a given state in the displayed field of view.

In yet another aspect, a method for assisting a user in guiding a medical instrument to a subsurface target site in a patient includes indicating a spatial feature of a patient target site on an intraoperative image, determining 3-D coordinates of the patient target site spatial feature in a reference coordinate system using the spatial feature of the target site indicated on the intraoperative image, determining a position of the instrument

in the reference coordinate system, projecting onto a display device a view field from a predetermined position relative to the instrument in the reference coordinate system, and projecting onto the view field an indicia of the spatial feature of the target site corresponding to the predetermined position.

Advantages of the system may include one or more of the following. The system enhances intra-operative orientation and exposure in endoscopy, in this way increasing surgical precision and speeding convalescence, which will in turn reduce overall costs. The ultrasound-enhanced endoscopy (USEE) improves localization of targets, such as peri-lumenal lesions, that lie hidden beyond endoscopic views. The system dynamically superimposes directional and targeting information, calculated from intra-operative ultrasonic images, on a single endoscopic view. Magnetic tracking and 3D ultrasound technologies are used in conjunction with dynamic 3D/video calibration and registration algorithms for precise endoscopic targeting. With USEE, clinicians use the same tools and basic procedures as for current endoscopic operations, but with a higher probability of accurate biopsy, and an increased chance for the complete resection of the abnormality. The system allows accurate soft-tissue navigation. The system also provides effective calibration and correlation of intra-operative volumetric imaging data with video endoscopy images.

Other advantages may include one or more of the following. The system acquires external 3D ultrasound images and process them for navigation in near real-time. The

system allows dynamic target identification on any reformatted 3D ultrasound cross-sectional plane. The system can automatically track the movement of the target as tissue moves or deforms during the procedure. It can dynamically map the target location onto the endoscopic view in form of a direction vector and display quantifiable data such as distance to target. Optionally, the system can provide targeting information on the dynamic 3D ultrasound view. The system can virtually visualize the position and orientation of tracked surgical tools in the ultrasound view, and optionally also in the endoscopic view. It can overlay dynamic Doppler ultrasound data, rendered using intensity based opacity filters, on the endoscopic view.

DESCRIPTION

Fig. 1 shows an exemplary process 5 to guide a medical instrument to a desired position in a patient. First, one or more intraoperative images of the target site are acquired (10). Next, the process registers the intraoperative images, the patient target site, and the surgical instruments into a common coordinate system (20). The patient, the imaging source(s) responsible for the intraoperative images and surgical tool must all be placed in the same frame of reference (in registration), and this can be done by one of a variety of methods, among them:

1. Use a wall-mounted tracking device for tracking patient, imaging source(s), and the surgical tool, e.g., endoscope.

2. Track only the position of the tool, and place the tool in registration with the patient and imaging source by touching the tool point to fiducials on the body and to the positions of the imaging source(s). Thereafter, if the patient moves, the device could be registered by tool-to-patient contacts. That is, once the images are made, from known coordinates, it is no longer necessary to further track the position of the image source(s).

3. The patient and image sources are placed in registration by fiducials on the patient and in the images, or alternatively, by placing the imaging device at known coordinates with respect to the patient. The patient and tool are placed in registration by detecting the positions of fiducials with respect to the tool, e.g., by using a detector on the tool for detecting the positions of the patient fiducials. Alternatively, the patient and an endoscope tool can be placed in registration by

imaging the fiducials in the endoscope, and matching the imaged positions with the position of the endoscope.

Referring back to Fig. 1, the process then tracks the position of the surgical instrument with respect to the patient target site (30). A magnetic tracking system is used to track the endoscope for navigation integration in one implementation. The system provides a magnetic transducer into the working channel at the endoscope tip, positioning the field generator so that the optimal sensing volume encompasses the range of sensor positions. In one implementation that provides for six degrees of freedom (6 DOF), a miniaturized magnetic tracking system with metal insensitivity known as miniBIRD 500 (available from Ascension Technology Corp. of Burlington, VT) can be used. The tracking system may be calibrated using a calibration jig. A calibration target is modified from a uniform to a non-uniform grid of points by reverse-mapping the perspective transform, so that the calibration target point density is approximately equal throughout the endoscope image. The calibration jig is waterproofed and designed to operate in a submerged environment. Where appropriate, calibration will be performed while the jig is immersed in a liquid with refractive properties similar to the operating environment.

In one embodiment, an ultrasound calibration system can be used for accurate reconstruction of volumetric ultrasound data. An optical tracking system is used to measure the position and orientation of a tracking device that will be attached to the ultrasound probe. A spatial calibration of intrinsic and extrinsic parameters of the ultrasound probe is performed. These parameters are used to transform the ultrasound image into the co-ordinate frame of the endoscope's field of view. In another embodiment, a magnetic tracking system is used for the ultrasound probe. Using only one

tracking system for both the endoscope and the ultrasound probe reduces obstructions in the environment, and avoids a line-of-sight tracking requirement. In another embodiment, tracking of the probe is done using an optical tracking system. The calibration of the 3D probe is done in a manner similar to a 2D ultrasound probe calibration using intensity-based registration. Intensity-based registration is fully automatic and does not require segmentation or feature identification. In the typical 2D case, acquired images are subject to scaling in the video generation and capture process. This transformation and the known position of the phantom's tracking device are used to determine the relationship between the ultrasound imaging volume and the ultrasound probe's tracking device. Successful calibration requires an unchanged geometry. The phantom will be designed to withstand relocation and handling without deformation. A quick-release clamp attached to the phantom will hold the ultrasound probe during the calibration process.

A spatial correlation of the endoscopic video with dynamic ultrasound images is then done. The processing internal to each tracking system, endoscope, and ultrasound machine causes a unique time delay between the realtime input and output of each device. The output data streams are not synchronized and are refreshed at different intervals. In addition, the time taken by the navigation system to acquire and process these outputs is stream-dependant. Consequently, motion due to breathing and other actions can combine with these independent latencies to cause real-time display of dynamic device positions different to those when the imaging is actually being acquired.

A computer is used to perform the spatial correlation. The computer can handle a larger image volume, allowing for increased size of the physical imaged volume or higher

image resolution (up to 512 × 512 × 512 instead of 256 × 256 × 64). The computer also provides faster 3D reconstruction and merging, and a higher-quality perspective volume rendering at a higher frame rate. The computer time-stamps and buffers the tracking and data streams, then interpolating tracked device position and orientation to match the image data timestamps.

In determining the required time offset, the ultrasound probe is moved across a step surface in the calibration phantom to create a temporal step function in both the tracking system and image data stream. The relative delay is determined by comparing the timestamps of the observed step function in each data stream. The endoscope latency is determined similarly using the same phantom. This should be performed whenever the ultrasound system is reconfigured. The endoscope latency will not need to be recalculated unless the endoscope electronics are changed, however. The patient is imaged through the ultrasound probe, and the endoscope becomes the frame of reference for the surgeon. The important information is contained in the dynamic relationship of the ultrasound data to the endoscope video, which is known through calibration and tracking of both devices.

Turning now to Fig. 1, one or more images of the patient target site are shown on a display device (40). A user indicates a spatial feature of the patient target site on the images of the patient target site (50), and an indicia is projected on the images relating the position and orientation of the surgical instruments to the spatial feature of the patient target site (60).

The method dynamically tracks and targets lesions in motion beyond the visible endoscopic view. When a target is identified, the subregion surrounding the target in the ultrasound volume will be stored as a reference, together with the tracked orientation of

the volume. A subregion of each successively-acquired ultrasound volume, centered at the target position in the preceding volume, will be re-sampled using the orientation of the reference target subregion. 3D cross-correlation of the re-sampled subregion with the reference subregion will be used to find the new location of the target. This dynamic tracking will follow each target over time; if the system is displaying target navigation data, the data will change in real time to follow the updated location of the target relative to the endoscope.

Vascular structures return a strong, well differentiated Doppler signal. The dynamic ultrasound data may be rendered in real time using intensity-based opacity filters, making nonvascular structures transparent. This effectively isolates the vascular structure without requiring computationally-demanding deformable geometric models for segmentation, thus the system can follow movements and deformations in real time.

The system of Fig. 1 allows a user such a surgeon to mark a selected target point or region on intraoperative ultrasonic images (one or more 3-D ultrasound images). The designated target point or region is then displayed to the surgeon during a surgical operation, to guide the position and orientation of the tool toward the target site. In a first general embodiment, the target area is displayed to the user by displaying a field representing the patient target area, and using the tracked position of the tool with respect to the patient to superimpose on the field, one or more indicia whose position in the displayed field is indicative of the relative position of the tool with respect to the marked target position. In a second general embodiment, the tool is equipped with a laser pointer that directs a laser beam onto the patient to indicate the position and orientation of

a trajectory for accessing the target region. The user can follow this trajectory by aligning the tool with the laser-beam.

In the embodiment where the tool is an endoscope, the displayed image is the image seen by the endoscope, and the indicia are displayed on this image. The indicia may indicate target position as the center point of the indicia, e.g., arrows, and tool orientation for reaching the target from that position, by the degree of elongation of arrows, such that the indicia are brought to equal sizes when the tool is properly oriented. Alternatively, the indicia may indicate the surface point for entry and the elongation of the arrows, the tool orientation-trajectory for reaching the target from that surface point.

In one embodiment that enables surgeons to visualize a field of view of the surgical endoscope overlaid with volumetrically-reconstructed medical images of a localized area of the patient's anatomy. Using this volumetric navigation system, the surgeon visualizes the surgical site via the surgical endoscope, while exploring the inner layers of the patient's anatomy through the three-dimensionally reconstructed pre-operative MRI or CT images. Given the endoscope's position and orientation, and given the characteristics of the camera, a perspective volume-rendered view matching that of the optical image obtained by the endoscope is rendered. This system allows the surgeon to virtually fly through and around the site of the surgery to visualize alternative approaches and qualitatively determine the best one. The volumetrically reconstructed images are generated using intensity based filtering and direct perspective volume rendering, which removes the need for conventional segmentation of high-contrast images. The real-time 3D-rendered radiographic reconstruction images matched with the intra-operative endoscopic images provide a new capability in minimally-invasive

endoscopic surgery. Since hitting vascular structures remains the greatest hazard in endoscopic procedures, this new technology represents a marked improvement over conventional image-guidance systems, which generally display 2D reconstructed images.

In operation, and with respect to an embodiment using ultrasonic images, the user makes a marking on the image corresponding to the target region or site. This marking may be a point, line or area. From this, and by tracking the position of the tool in the patient coordinate system, the system functions to provide the user with visual information indicating the position of the target identified from the ultrasonic image.

The navigation system operates in three distinct modes. The first is target identification mode. The imaged ultrasound volume will be displayed to allow the surgeon to locate one or more target regions of interest and mark them for targeting. The system will show an interactive volumetric rendering as well as up to three user positionable orthogonal cross-sectional planes for precise 2D location of the target.

In the second mode, the endoscope will be used to set the position and orientation of the frame of reference. Based on these parameters and using the optical characteristics of the endoscope, the system will overlay target navigation data on the endoscope video. This will allow the surgeon to target regions of interest beyond the visual range of the endoscope's field of view. Displayed data will include the directions of, and distances to, the target regions relative to the endoscope tip, as well as a potential range of error in this data.

The third mode will be used to perform the actual interventional procedure (such as biopsy or ablation) once the endoscope is in the correct position. The interactive imaged ultrasound volume and cross-sectional planes will be displayed, with the location

of the endoscope and the trajectory through its tip projected onto each of the views. The endoscope needle itself will also be visible in the ultrasound displays.

The system allows the interventional tool to be positioned in the center of the lesion without being limited to a single, fixed 2D ultrasound plane emanating from the endoscope tip. (That 2D view capability can be duplicated by optionally aligning a cross sectional ultrasound plane with the endoscope.) In the first implementation of the endoscope tracking system, a magnetic sensor will need to be removed from the working channel in order to perform the biopsy, and the navigation display will use the stored position observed immediately prior to its removal. In another embodiment, a sensor is integrated into the needle assembly, which will be in place at calibration.

The system provides real-time data on the position and orientation of the endoscope, and the ultrasound system provides the dynamic image data. The tip position data is used to calculate the location of the endoscope tip in the image volume, and the probe orientation data will be used to determine the rendering camera position and orientation. Surgeon feedback will be used to improve and refine the navigation system. Procedure durations and outcomes will be compared to those of the conventional biopsy procedure, performed on the phantom without navigation and image-enhanced endoscopy assistance.

When a target is identified, the subregion surrounding the target in the ultrasound volume will be stored as a reference, together with the tracked orientation of the volume. A subregion of each successively-acquired ultrasound volume, centered at the target position in the preceding volume, will be re-sampled using the orientation of the reference target subregion.

3D cross-correlation of the re-sampled subregion with the reference subregion will be used to find the new location of the target. This dynamic tracking will follow each target over time; if the system is displaying target navigation data, the data will change in real time to follow the updated location of the target relative to the endoscope.

Fig. 2 shows another exemplary implementation where a process 100 acquires one or more 2D or 3D intraoperative images of the patient target site from a given orientation (110). Next, the process tracks the position of a surgical instrument with respect to the patient target site (120). The process then registers the intraoperative images of the patient site, the patient target site, and the surgical instrument into a common 3D reference coordinate system (130). The image of the patient target site is rendered on a display device (140), and a spatial feature (shape and position)of the patient target site on the image is specified (150). The process then correlates the position and orientation of the surgical instrument with respect to the target feature (160). An indicia (3D shape or points and lines) is projected on the intraoperative image relating the position and orientation of the surgical instrument to the target spatial feature (170).

Exemplary user interfaces for the systems of Figs. 1-2 are shown in Figs. 3-4. Fig. 3 shows an exemplary user interface (UI) for ultrasound-enhanced endoscopy. The left panel shows the endoscopic view with a superimposed targeting vector and a distance measurement. The right panels show reformatted crosssectional planes through the acquired 3D ultrasound volume. Fig. 4 shows another UI for ultrasound-enhanced endoscopy. The left panel shows the endoscopic view with virtual tool tracking and visualization and vasculature acquired through Doppler imaging. The lower right panel shows volume-rendered 3D ultrasound.

The UIs of Figs. 3-4 support interactive rendering of the ultrasound data to allow a user to locate and mark the desired region of interest in the ultrasound image volume. The UIs allow the user to locate and mark target regions of interest. Hitting vascular structures is a serious hazard in endoscopic procedures. Visualization of the vasculature behind the surface tissue in the endoscopic view would assist in avoiding the vascular structures (anti-targeting).

The invention has been described in terms of specific examples which are illustrative only and are not to be construed as limiting. The invention may be implemented in digital electronic circuitry or in computer hardware, firmware, software, or in combinations of them. Apparatus of the invention may be implemented in a computer program product tangibly embodied in a machine-readable storage device for execution by a computer processor; and method steps of the invention may be performed by a computer processor executing a program to perform functions of the invention by operating on input data and generating output. Suitable processors include, by way of example, both general and special purpose microprocessors. Storage devices suitable for tangibly embodying computer program instructions include all forms of non-volatile memory including, but not limited to: semiconductor memory devices such as EPROM, EEPROM, and flash devices; magnetic disks (fixed, floppy, and removable); other magnetic media such as tape; optical media such as CD-ROM disks; and magneto-optic devices. Any of the foregoing may be supplemented by, or incorporated in, specially-designed application-specific integrated circuits (ASICs) or suitably programmed field programmable gate arrays (FPGAs).

From the a foregoing disclosure and certain variations and modifications already disclosed therein for purposes of illustration, it will be evident to one skilled in the relevant art that the present inventive concept can be embodied in forms different from those described and it will be understood that the invention is intended to extend to such further variations. While the preferred forms of the invention have been shown in the drawings and described herein, the invention should not be construed as limited to the specific forms shown and described since variations of the preferred forms will be apparent to those skilled in the art. Thus the scope of the invention is defined by the following claims and their equivalents.

ABSTRACT

Systems and methods are disclosed for assisting a user in guiding a medical instrument to a subsurface target site in a patient by indicating a spatial feature of a patient target site on an intraoperative image, determining 3-D coordinates of the patient target site spatial feature in a reference coordinate system using the spatial feature of the target site indicated on the intraoperative image, determining a position of the instrument in the reference coordinate system, projecting onto a display device a view field from a predetermined position relative to the instrument in the reference coordinate system, and projecting onto the view field an indicia of the spatial feature of the target site corresponding to the predetermined position.

10-Generate intraoperatve image/s of the target site.

20- Register the intraoperative images, the patient target site, and the surgical instruments into a common coordinate system

30- Track the position of the surgical instrument with respect to the patient target site

40- Generate image/s of the patient target site on a display device

50- Indicate a spatial feature of the patient target site on the images of the patient target site

60- Project indicia on the images relating the position and orientation of the surgical instruments to the spatial feature of the patient target site

FIG. 1

110) Generate a 2D or 3D intraoperative images of the patient target site from a given orientation

120) track the position of a surgical instrument with respect to the patient target site

130) Register the intraoperative images of the patient site, the patient target site, and the surgical instrument into a common 3D reference coordinate system

140) Display image of the patient target site on a display device

150) Specify a spatial feature (shape and position)of the patient target site on the image

160) Correlate the position and orientation of the surgical instrument with respect to the target feature

170) Project indicia (3D shape or points and lines) on the intraoperative image relating the position and orientation of the surgical instrument to the target spatial feature

FIG. 2

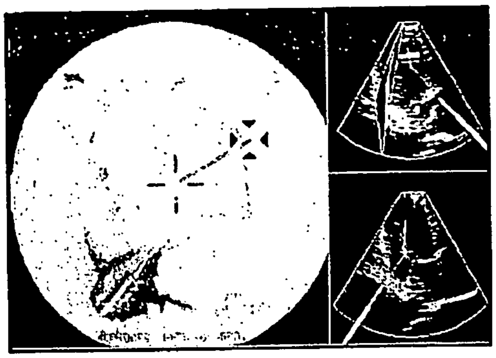

FIG. 3

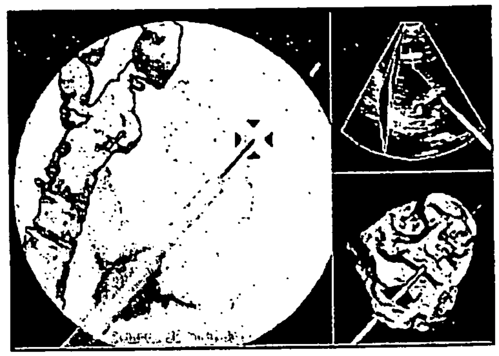

FIG. 4

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